Issues of ICRF Heating System in LHD

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LHD ICRF heating specification

Antenna types Antenna	Loop Antenna	Folded Wave Guide
Wave Excitation	Fast Wave High Field Side	IBW or $E_{//}$ production Low Field Side
Pulse Length	Steady State	Steady State
Power	2.7 MW (4th cycle) 12 MW	0.4 MW
Frequency 65.0 MHz	25-60 MHz	25.1, 37.4, 41.5,
LHD ports	Vertical top and bottom	Outside Horizontal

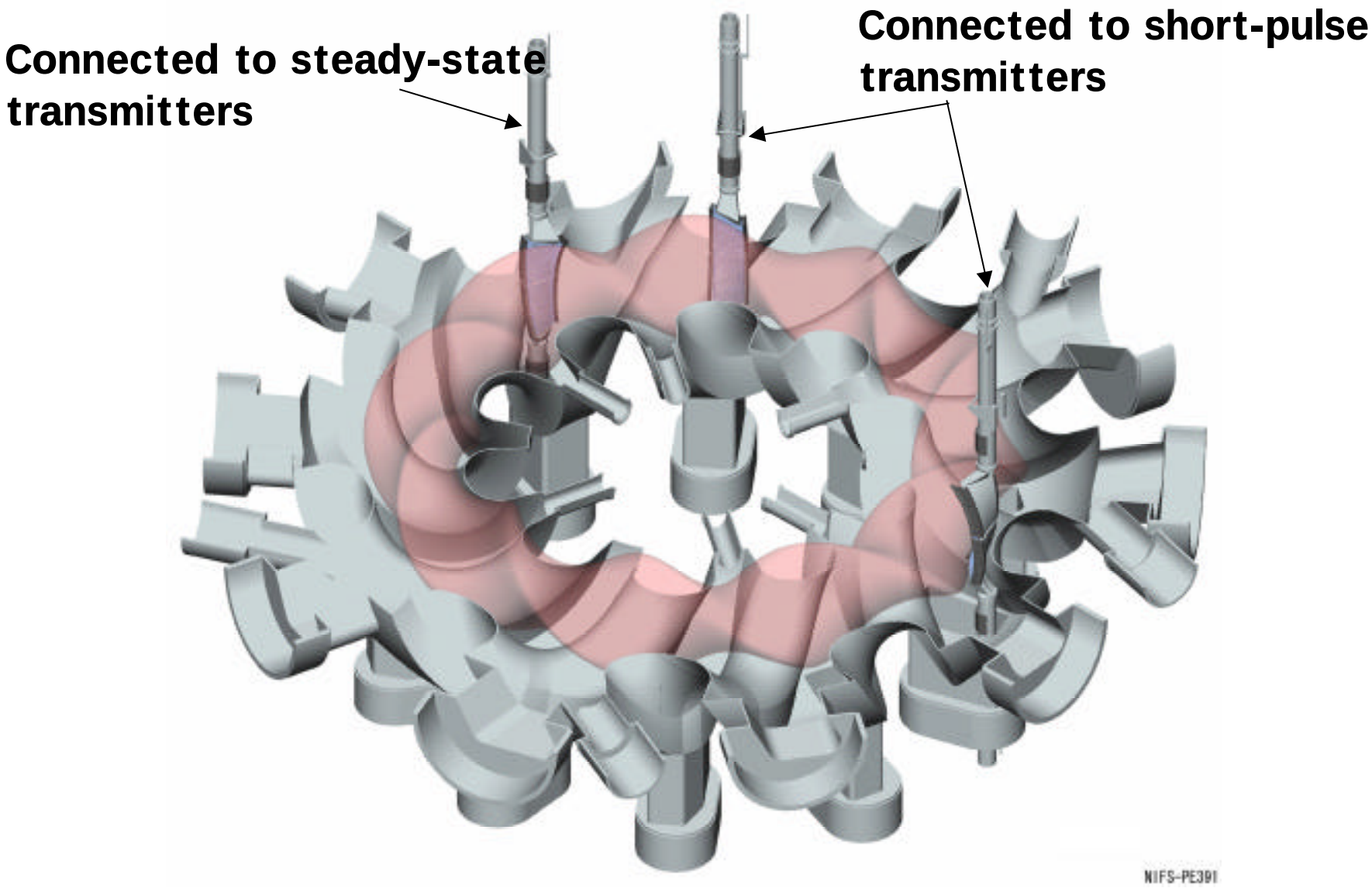
Outline

- loop antenna
  - Temperature rise
  - Damage at bolt and Faraday shield
- impedance matching system
  - Metal contact finger of conventional stub
  - Teflon in liquid
- feedthrough
  - Shape of ceramics
- folded waveguide antenna
  - Feed point
- Summary

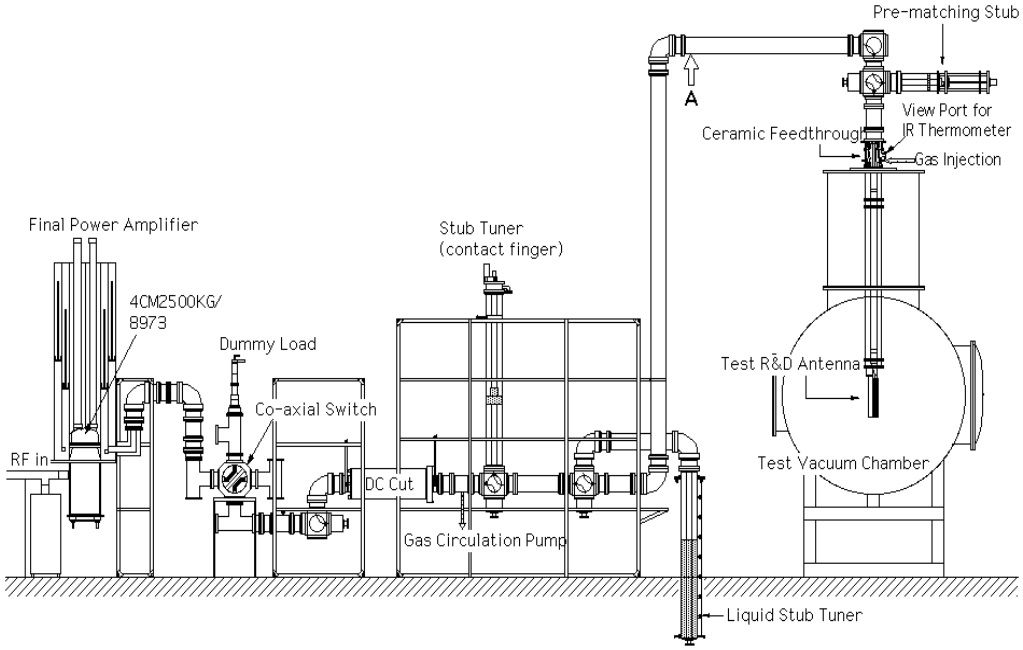
Features of fast wave antenna (loop antenna) for LHD

- Installed from top and bottom port
  - launch from high B field and outward side
- Single strap loop
  - twisted to fit the LHD plasma shape
- Sizes of launcher
  - length 60 cm
  - total width 46 cm
  - center strap width 30 cm
- All parts are water cooled
- Radial antenna position is movable by 16 cm

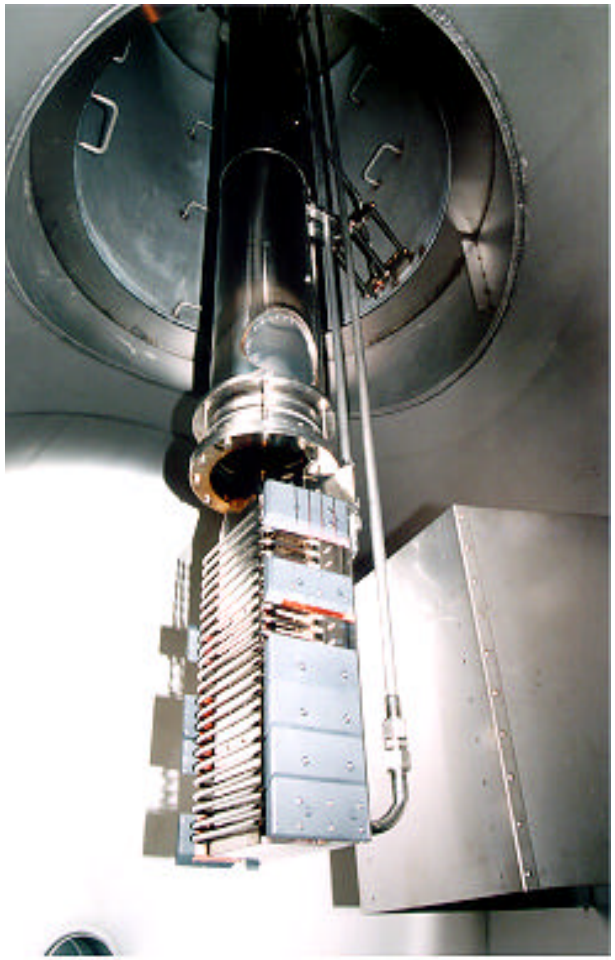
Installed loop antennas in LHD



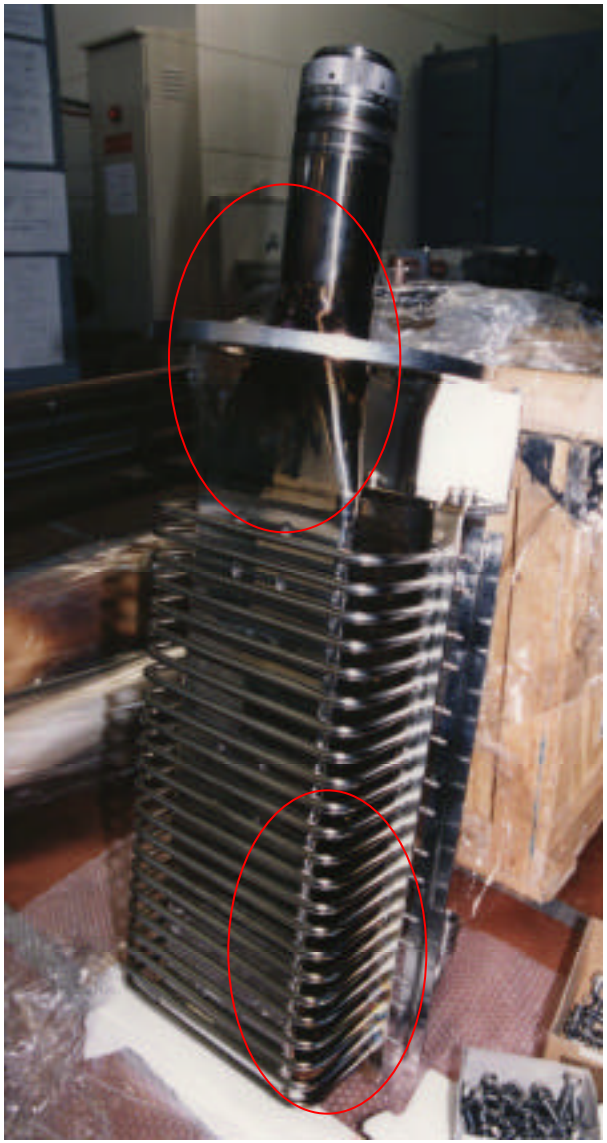
High power steady state antenna was developed in test vacuum chamber

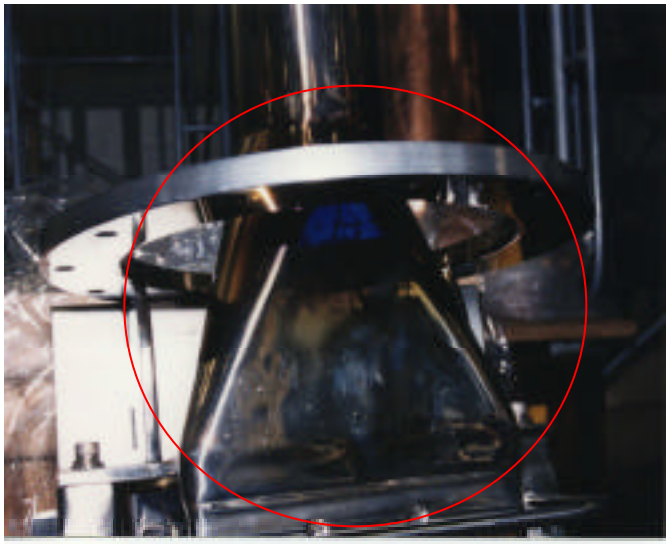


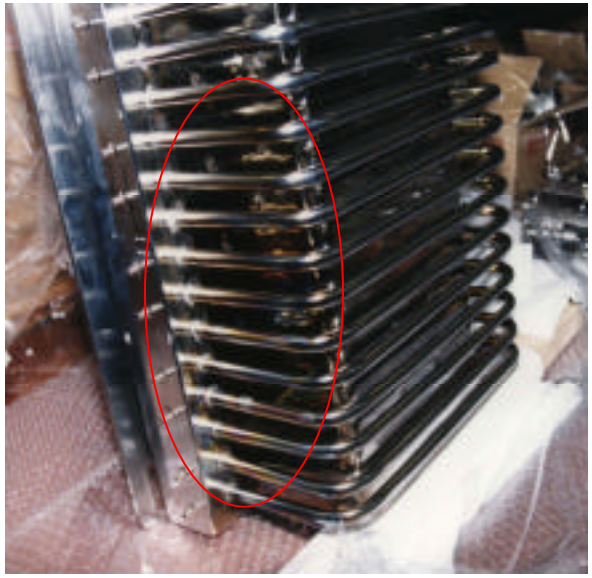
ICRF test antenna in the test vacuum chamber



Color of antenna surface was changed in vacuum operation

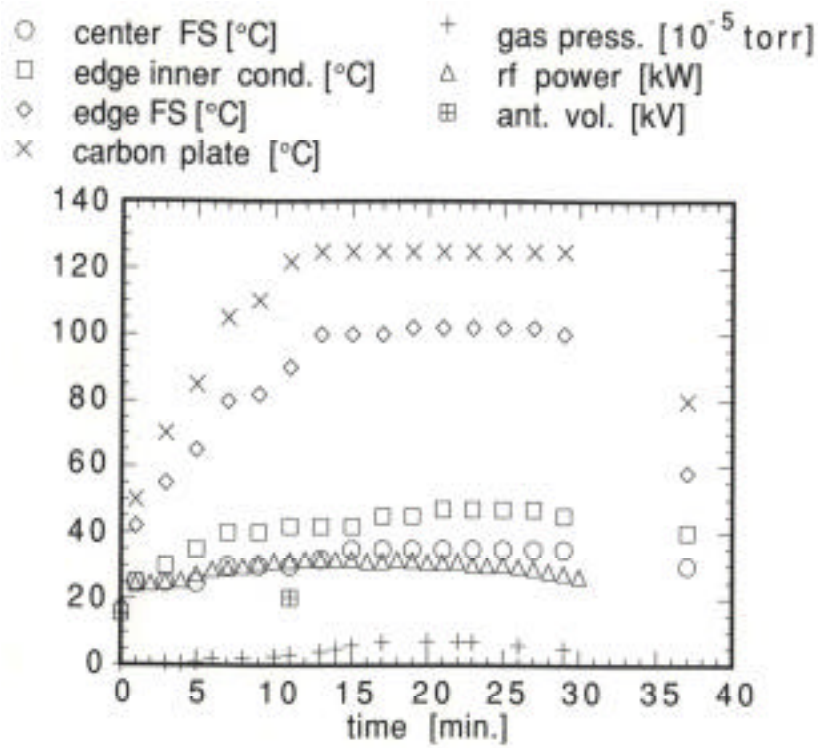






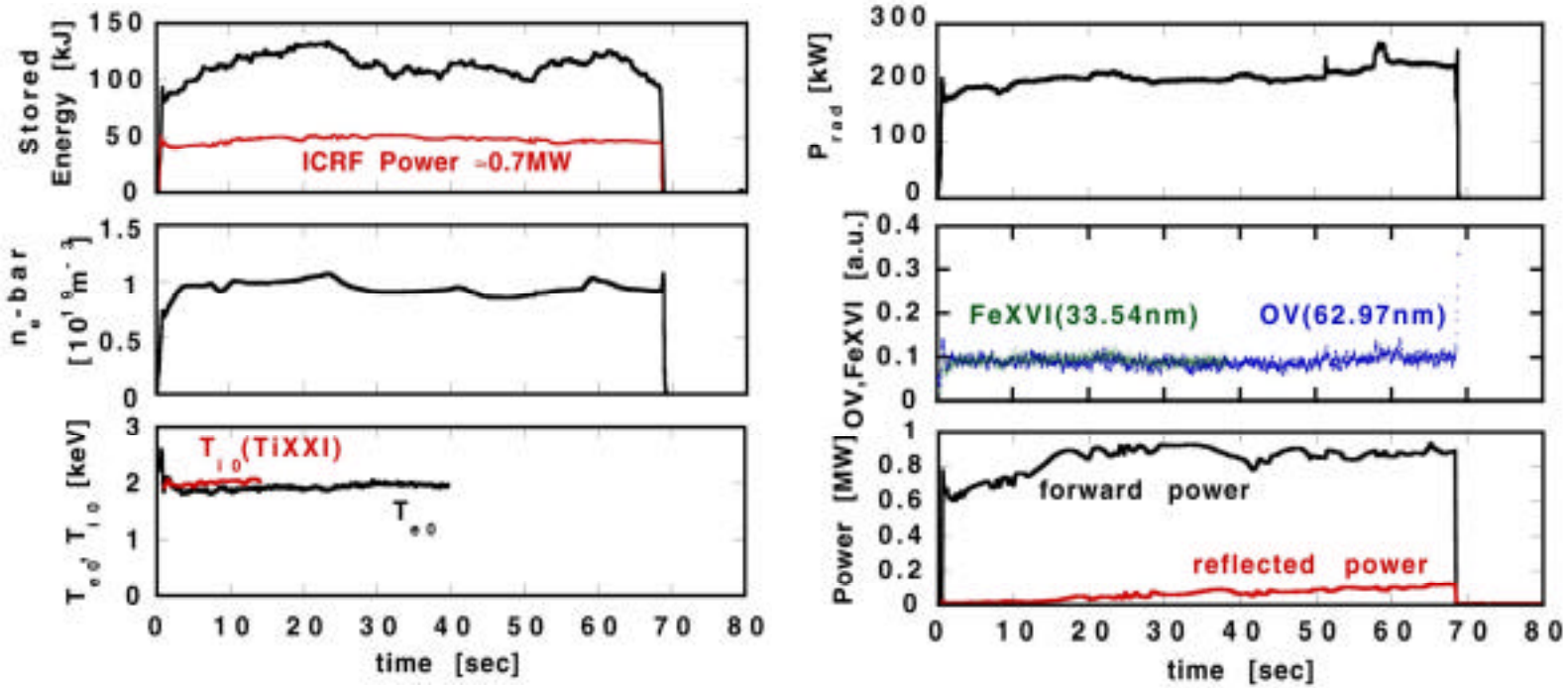
- R & D experiment in vacuum
- Temperature increased partially
- Temperature at antenna side was higher than that of center region

Temperature increase in R & D antenna (vacuum test)



- Temperature at carbon plate is highest
- Corner edge of Faraday shield also becomes high temperature
- Temperature saturates in 10 minutes
- RF-induced current is the source of heat

Plasma is sustained for 68 seconds by ICRF heating only



– ICRF power of 0.7 MW was injected into the plasma for 68 seconds

– Plasma was sustained by only ICRF heating

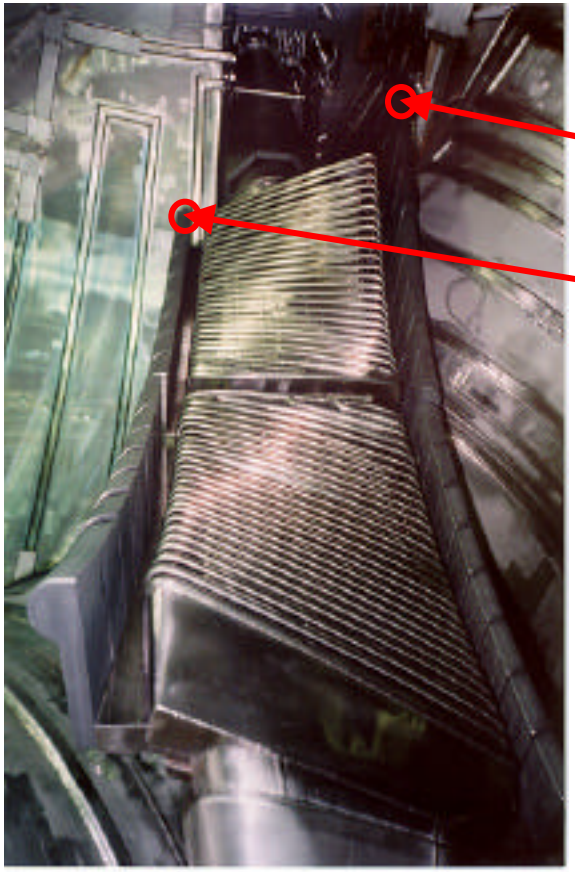
– Density, temperature and radiation loss power kept constant; longer pulse length will be possible

– Pulse length was determined by transmitter

- Conditioning of transmitter for long pulse operation was not enough

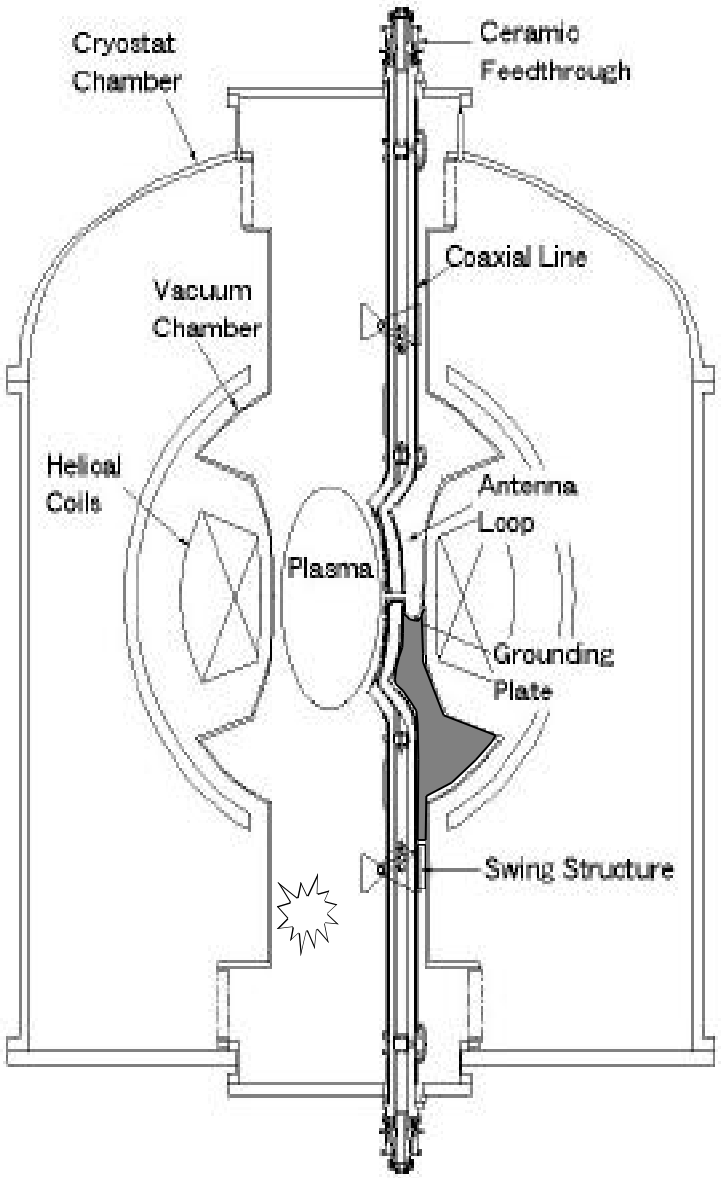
Hot spot was observed at the carbon protectors in the 68 seconds operation (3rd cycle experiment)

Just after the end of ICRF power

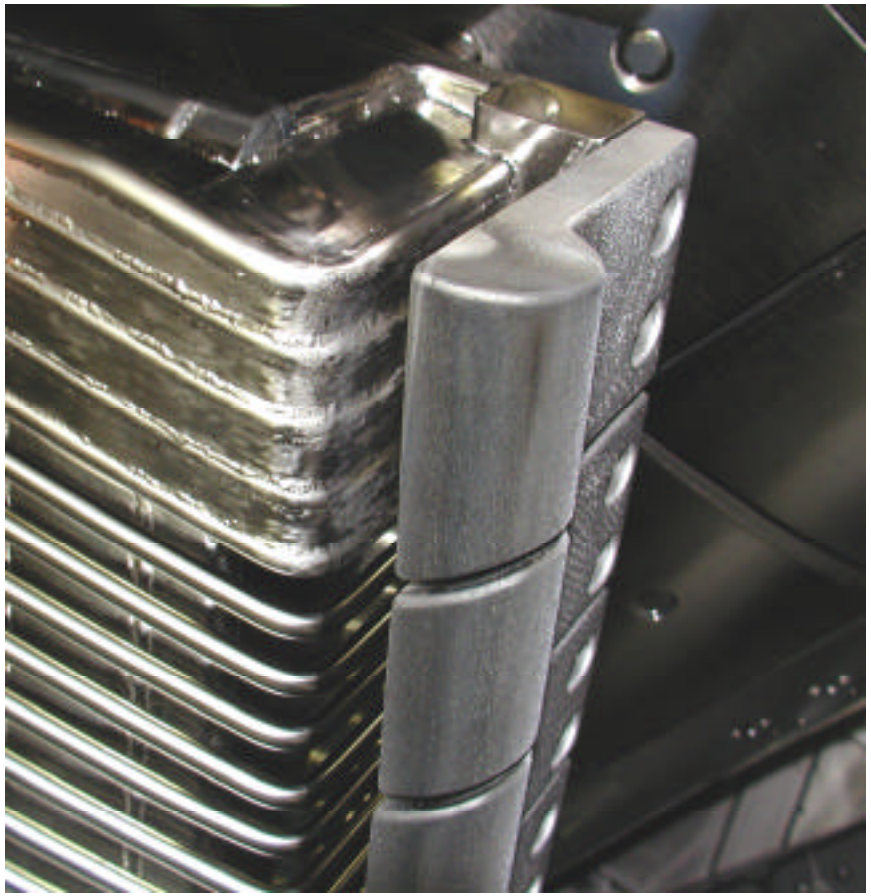


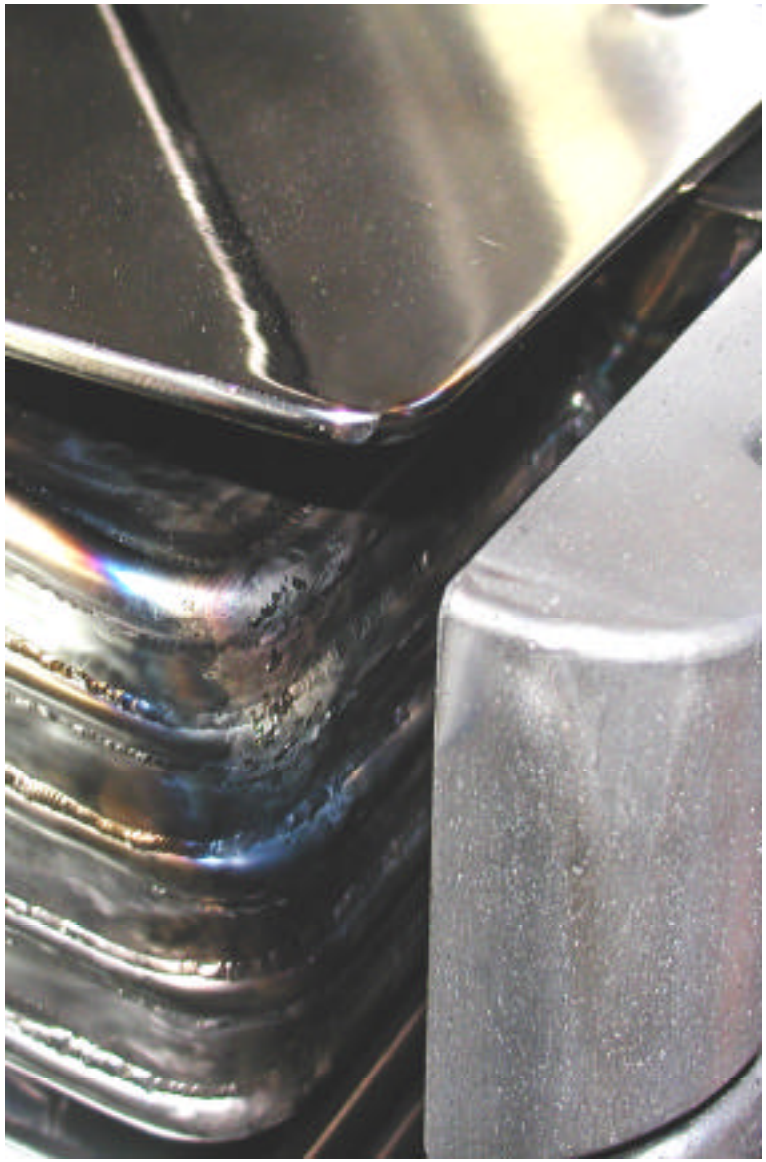
– We will inspect the carbons and modify them in this vacuum break
– However, we don not think this is a serious problem

Supporting bolt is broken (melted)



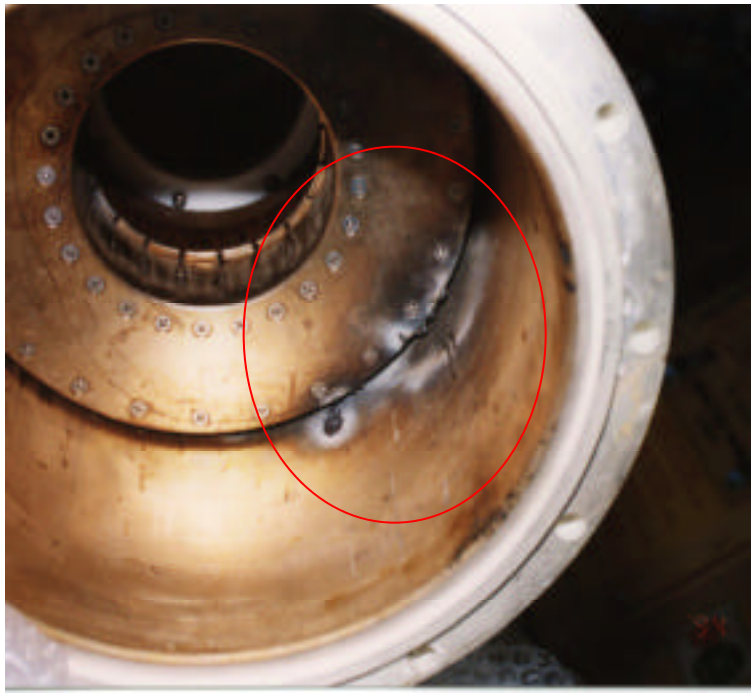
Damage was found at the corner of the cover of Faraday shield

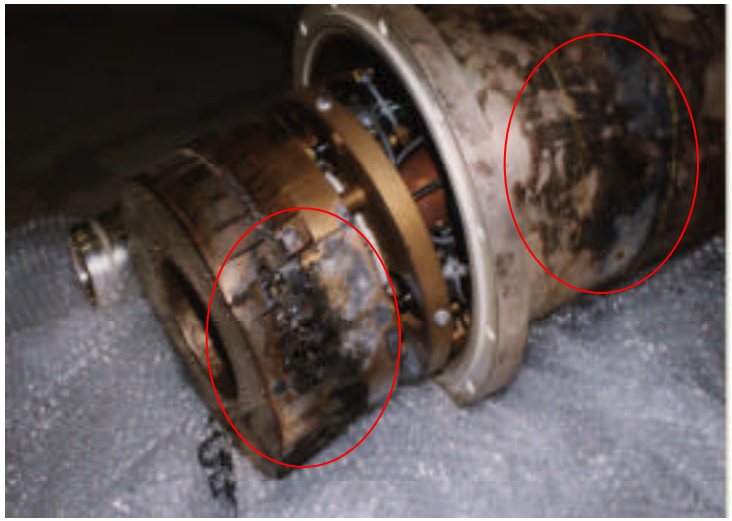


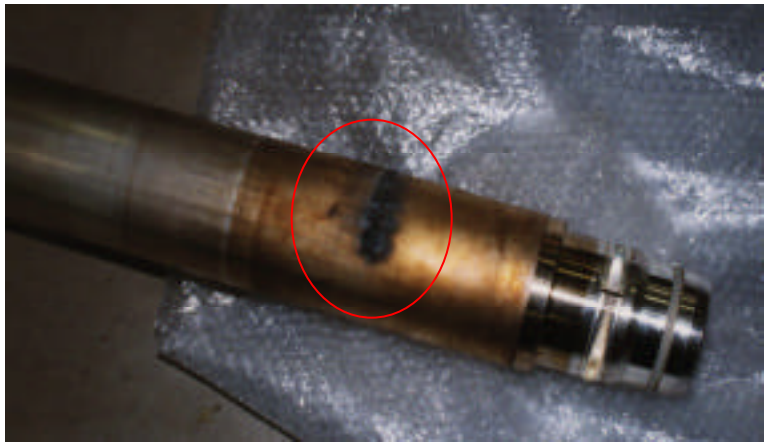


- Protrude carbon protector moreover in next experiment

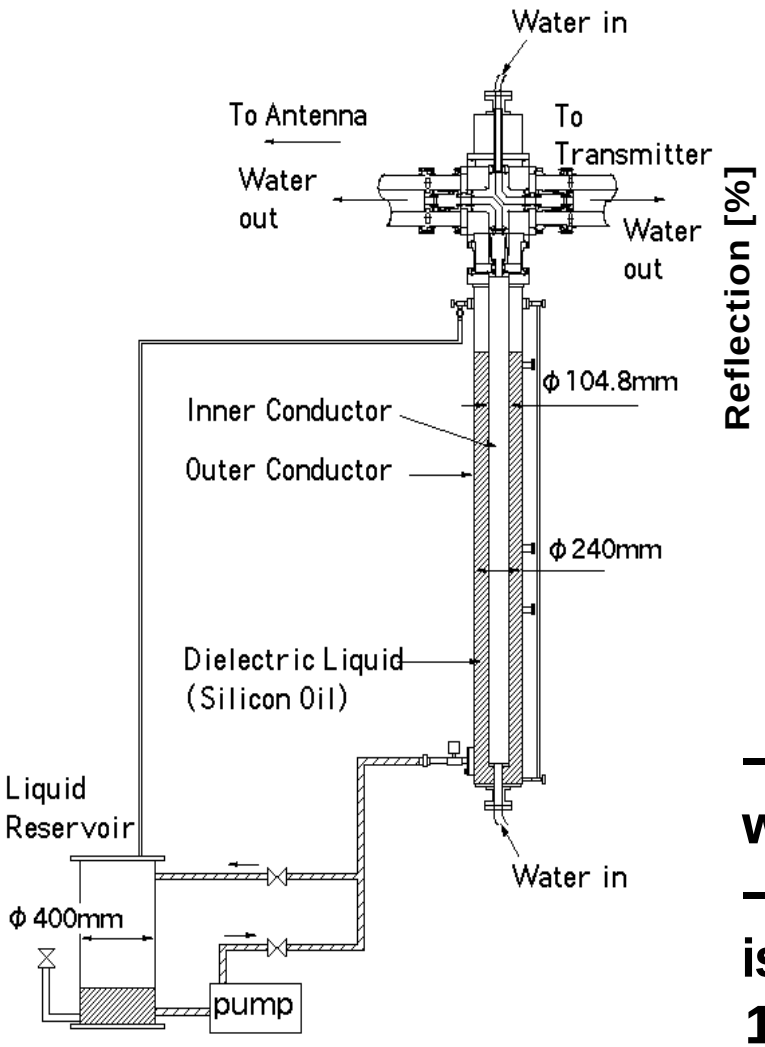
Metal contact finger of conventional stub was damaged seriously in long pulse operation

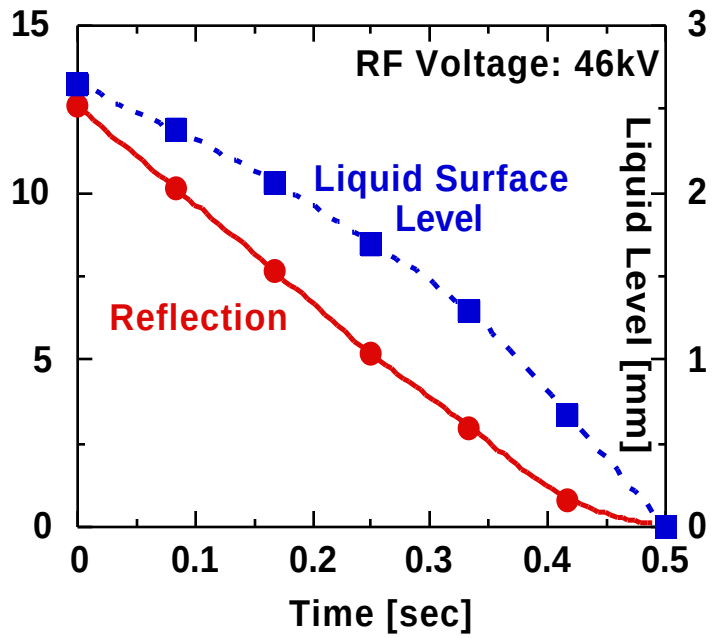






Liquid stub tuner was developed for steady state operation



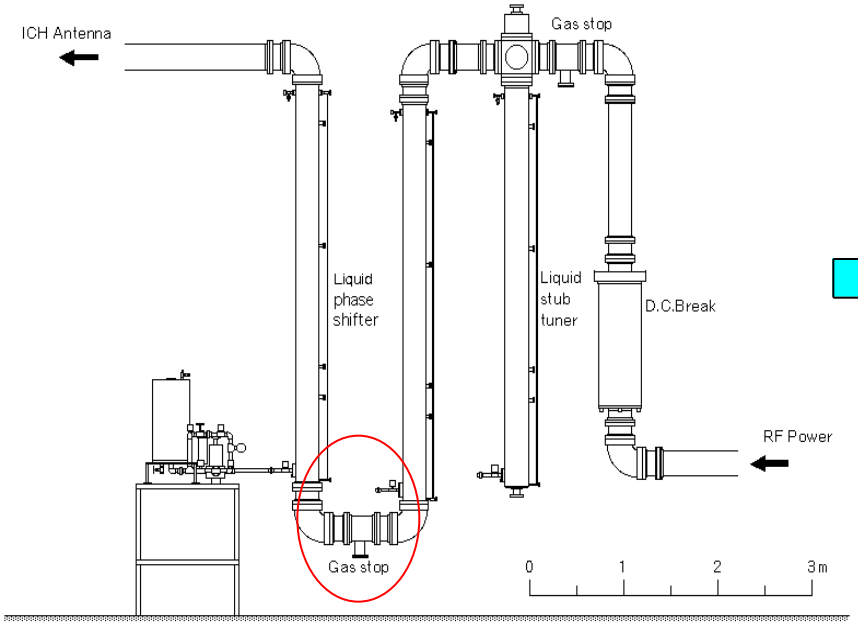


– Using the difference between the rf wavelengths in liquid and in gas

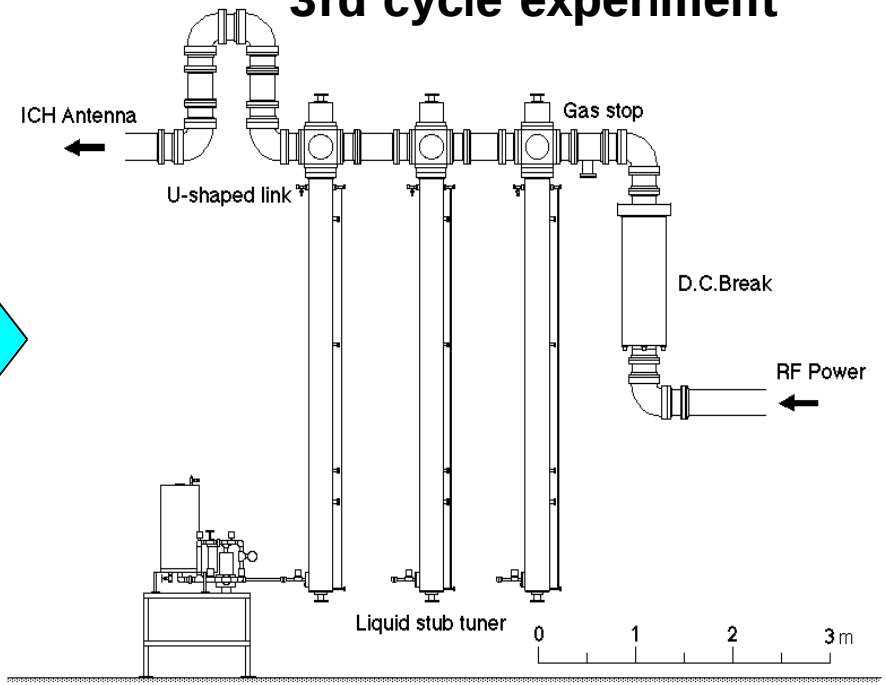
– Relative dielectric constant of liquid is 2.72 and dielectric loss is less than 1 %

Liquid stub tuner was applied to the LHD experiment

2nd cycle experiment



3rd cycle experiment



– Configuration of the impedance matching system was changed because supporting teflon spacer in liquid caused rf breakdown sometimes

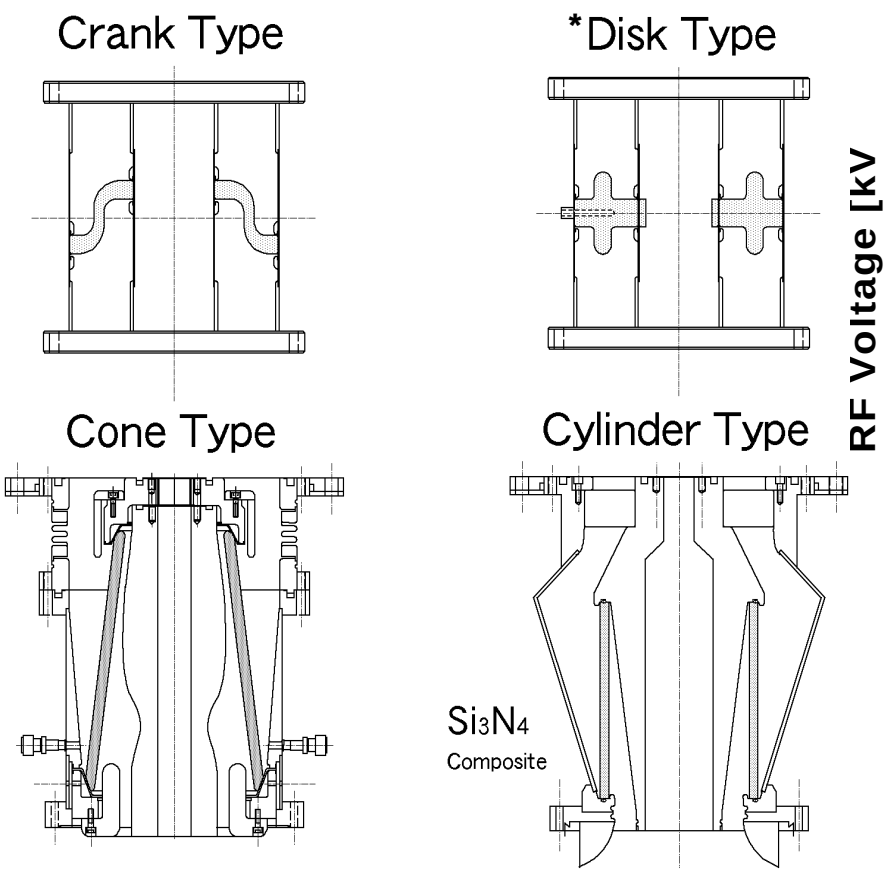
Double liquid stub tuner

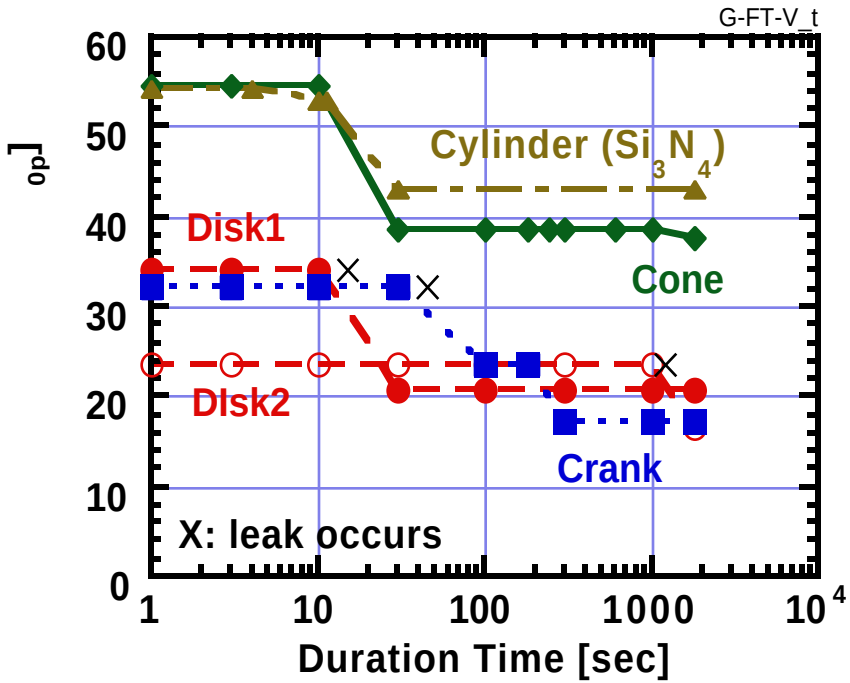
- Newly manufactured for new antennas

- Height is about 7 m and the stroke is 6 m

Several kinds of ceramic feedthrough were tested for steady state operation

Cross sections of tested feedthroughs



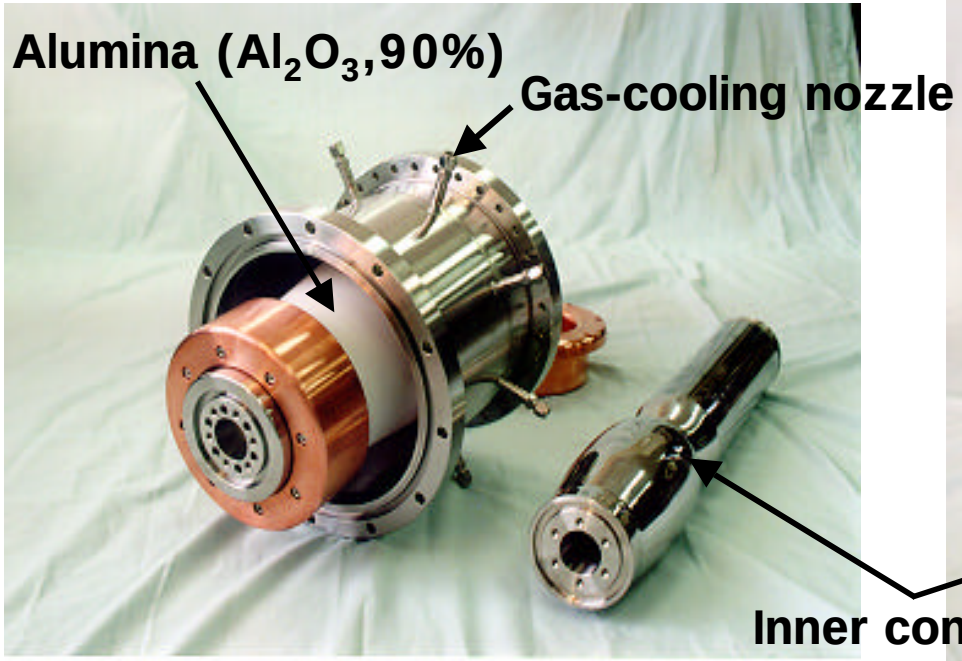


*Disk1 has cooling duct inside the ceramics
Disk2 has no cooling channel

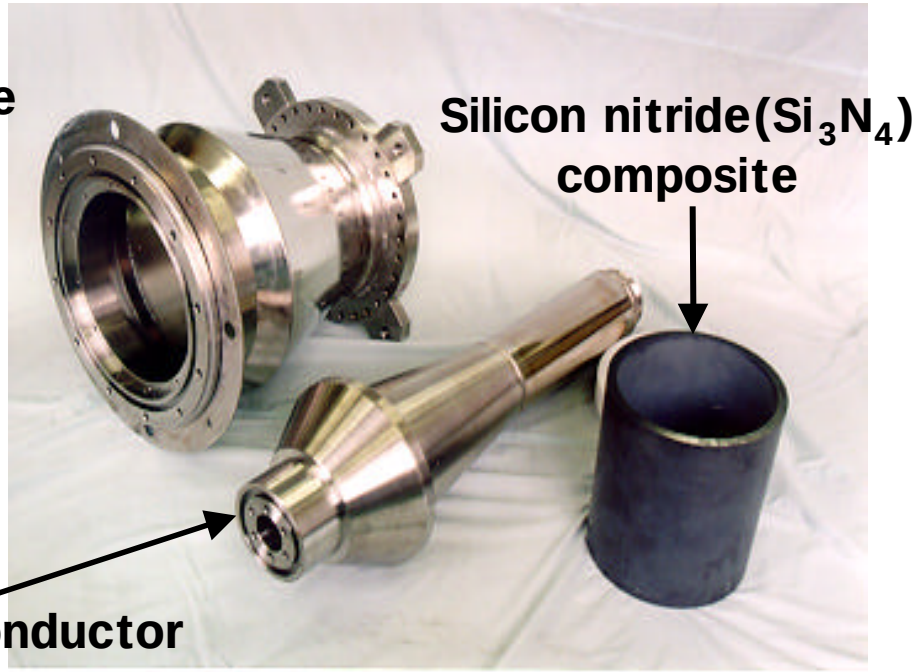
- **Cone and cylinder type had enough capability for steady state operation**
- **The operational limit was determined by the pressure rise in the test chamber**

Photographs of the tested feedthroughs

Cone type feedthrough



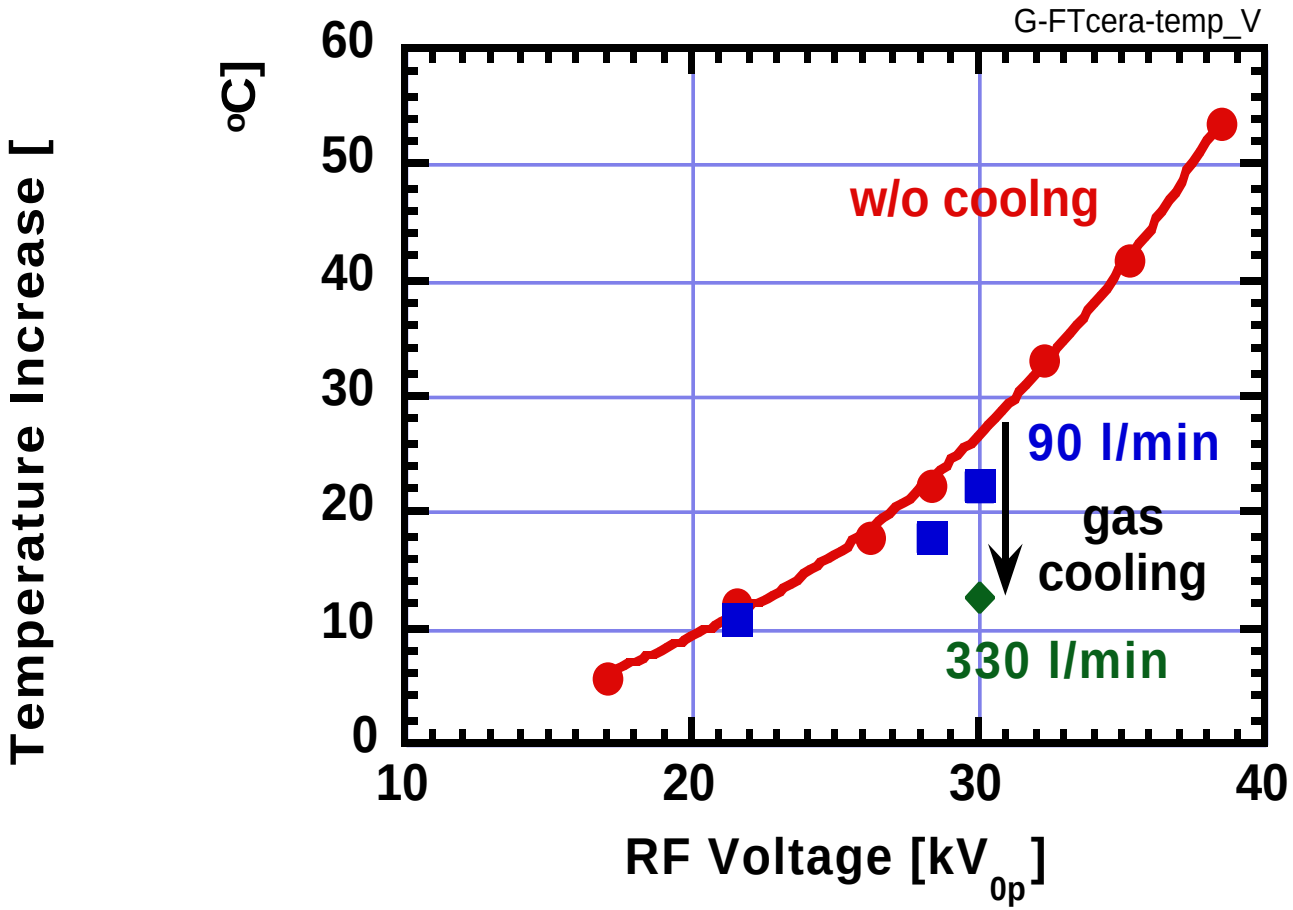
Cylinder type feedthrough



– Cone type feedthrough is selected for LHD ICRF system

– O-ring is used for vacuum seal to avoid the crack on the brazing seal (no brazing)

Ceramic temperature on feedthrough can be suppressed by gas cooling on surfac



Summary of R & D for the steady state ICRF heating system

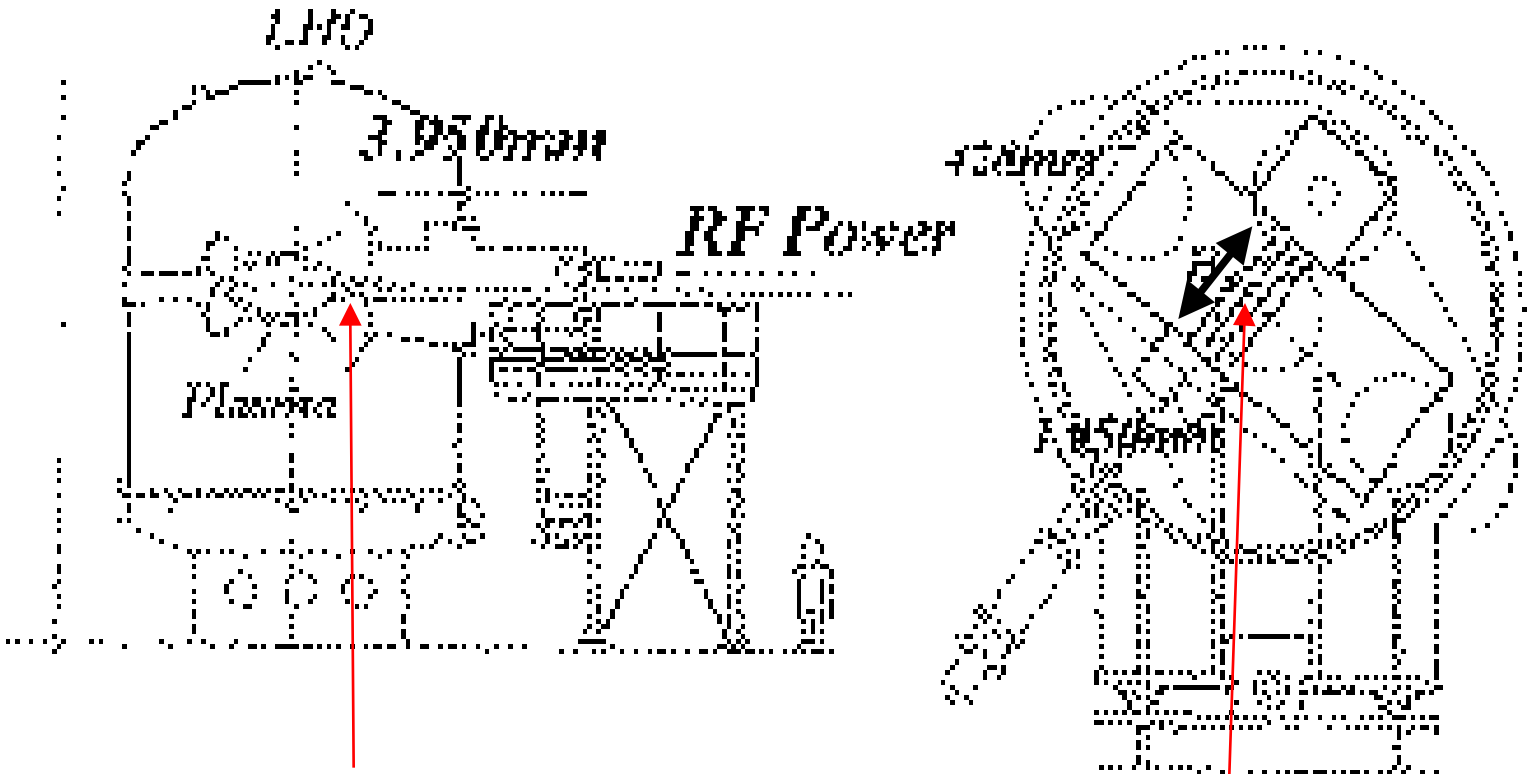
Transmitter	1.6 MW, 5000 seconds
Coaxial Transmission Line	50 kV, 30 minutes
Impedance Matching System	50 kV, 30 minutes
Feedthrough	40 kV, 30 minutes
Antenna	40 kV, 30 minutes

40 kV ---> 1.6 MW (5 ohm)
50 kV ---> 2.5 MW (5 ohm)

Folded Waveguide Antenna in LHD

- Designed and fabricated for horizontal port
  - collaboration with ORNL
- Dimensions:
  - length: 3950 mm, width: 1050 mm, height: 428 mm
  - 24 folds and 23 vanes
- Resonant frequencies:
  - 25.1 MHz, 37.4 MHz, 41.5 MHz, 65.0 MHz
- Wave number spectrum
  - $k_{//}$=3 to 12m^{-1} (by changing polarization plate)
- Antenna front is fitted to last closed flux surface
- Horizontally movable by 1.15 m

FWGA system



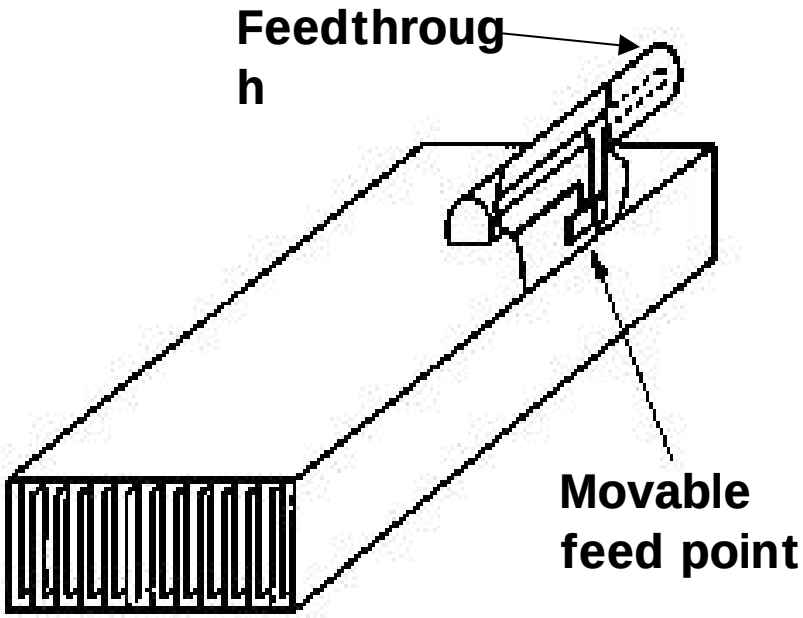
Cross X-point in using

(problem in helical structure)

slanted movable feed point

Mechanism of electric feed of FWGA

- Using movable feed point in vacuum initially
- After plasma operations (He-glow discharges) feed point became immovable
- Changed to fixed feed point
  - External circuit is added for impedance matching



Summary

- Concerning loop antenna, damage at supporting bolt and cover of Faraday shield is serious
  - Try to fix it in this vacuum break
  - Heat at carbon and antenna side may not be serious problem for a while
- After eliminating liquid phase shifter, we do not have any problem so far
- We do not have any problem about cone type of ceramic feedthrough from the start of experiment
- We will increase power and pulse length moreover
  - 1 MW/more than 2 min., 0.6 MW/more than 5min.